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Abstract

The present paper investigates Bradford’s Law of scattering for the ‘Microbiology’ literature in India for the period 2002-2016 as accessible in the Web of Science Core Collection database. A total of 25,744 articles related to Microbiology literature published in journals during the study period is retrieved. The data has been examined with respect to year-wise publication productivity, Relative Growth Rate (RGR) and Doubling Time (DT) of literature. The time series analysis is also used to predict the future growth of literature. The 25,744 articles are scattered in 328 journals. A top ranked journals list was prepared and it unveiled that the Bio-resource Technology Journal has emerged as the most preferred journal with 1,610 (6.25%) articles followed by Applied Biochemistry and Biotechnology with 1,019 (3.95%) articles and World journal of Microbiology Biotechnology with 746 (2.89%) articles.

Theoretical aspects of Bradford’s Law of Scattering are verified and manifested that the data does not fit to the present sample. The Leimkuhler model is applied and it proved to the data set for the Bradford Multiplier (k) at 14.17. The Bradford law is also verified through graphical formulation by drawing the graph and is found to approve all the three characteristics.

Keywords – Bradford’s Law, Journal Ranking, Citation study, Relative Growth Rate, Doubling Time, Microbiology

1. Introduction

The subject Microbiology is the field of biological science that studies the microscopic organisms, for example, bacteria, viruses, archaea, prions, algae, fungi, and protozoa. These microorganisms are together known as 'microbes' (*Microbiology*, n.d.). The microbes are responsible for biodegradation/bio deterioration, nutrient cycling, food spoilage, climate change, the origin and resistor of disease, and biotechnology (Microbiology Society, n.d.). Microbiology research has always been predominant area of research in India, because it is vital to consulting several contemporary global objectives and challenges, such as upholding the safety of food, water, and energy for a healthy population on the inhabitable earth (Lal, 2012).

As a subject microbiology is growing due to the vast research enduring in various facades in the world (Gillen and Oliver, 2012). Following to this, there is a radical growth of research output through numerous formats such as journal articles, conference papers, books, research reports and so on. Every arena of research has limited journals (core journals) where researchers desire to publish their research paper. Bibliometric techniques are useful in determining various scientific indicators, assessment of scientific productivity, procuring of journals to the libraries and projecting the latent of a field (Kattimani, 2012). In this paper, an effort is made to disclose the research tendencies in Microbiology and to recognize the core journals in the subject by applying the Bradford's Law of Scattering.

2. Objectives

The objectives of the present study are to:

- prepare the rank list of most productive journals in Microbiology research publications
- examine the relative growth rate and doubling time
- estimate the future growth
- identify the core journals by applying the Bradford's Law

3. Methodology

Required data for the study has been gathered from Web of Science database. The database has been searched with the keyword as 'Microbiology' in the 'Title' for the period 2002-2016 and 25,744 articles published in 328 journals with bibliographic details were downloaded for analysis.

4. Results

4.1 Growth of articles

Table 1 shows the year-wise distribution of articles. It is perceived from Table 1 that the highest number of 2,602 (10.11%) articles are published in the year 2016, followed by 2,567 (9.97%) in 2014 and 2,520 (9.79%) in 2015. Though the number of papers published each year is not steady but excluding for the few years the research output in Microbiology is dependably increasing.

Table 1-Year-wise Distribution of articles

Year	Papers	Percentage of 25,744
2002	676	2.63
2003	699	2.72
2004	726	2.82
2005	898	3.49

2006	1,062	4.13
2007	1,246	4.84
2008	1,791	6.96
2009	1,890	7.34
2010	1,983	7.70
2011	2,350	9.13
2012	2,337	9.08
2013	2,397	9.31
2014	2,567	9.97
2015	2,520	9.79
2016	2,602	10.11
Total	25,744	100

4.2 Relative Growth Rate and Doubling Time

The RGR is the increase in number of articles/pages/reports/patents per unit of time. This definition is taken from study of growth analysis of individual plants and successfully applied in the field of Botany (Hunt, 1978) which in turn had its origin form the study of the rate of interest in the financial investments by Blackman (1919). The mean Relative Growth Rate (R) can be calculated form the following equation.

$1 - 2^{R} = (Log_e W_2 - Log_e W_1)/(T2 - T1)$

where,

1 – 2R = Mean relative growth rate over the specific period of interval

LogeW1 = log of initial number of articles

LogeW2 = log of final number of articles after a specific period of interval

T2 – T1 = Unit difference between the initial time and the final time

aa^{-1} = average number of articles

The RGR for articles is hereby calculated as below.

1 – 2R (aa–1 year–1) can represent the mean RGR per unit of articles per unit of year over a specific period of interval.

$2002 = \frac{Log_e(1326) - Log_e(650)}{2003-2002}$

$$= \frac{7.19-6.48}{1} = \frac{0.71}{1}$$

2003 = 0.71

$$2003 = \frac{Log_e(2025) - Log_e\,(1326)}{2004-2003}$$

$$= \frac{7.61-7.19}{1} = \frac{0.42}{1}$$

2004 = 0.42

Likewise, the relative growth rate for other years is also calculated (Table 2). The mean relative growth rate is 0.24.

Doubling Time (DT)

There is a correspondence between the RGR and the DT. If the total number of research articles of a scientific field twofold during the study period, then the difference between the log numbers at the beginning year and end of the study period must be log number 2. Here, if we use natural logarithm the changed value is 0.693. Thus, the doubling time can be calculated by using the formula:

$$\text{Doubling time (DT)} = \frac{0.693}{\text{R}}$$

Therefore,

Doubling time for articles:

$$\text{Dt (a)} = \frac{0.693}{1-2\text{R (aa}-1\text{ year}-1)}$$

$$\mathbf{2003} = \frac{0.693}{0.71} = \mathbf{0.98}$$

$$\mathbf{2004} = \frac{\mathbf{0.693}}{\mathbf{0.42}} = \mathbf{1.65}$$

In the same way, doubling time for other years is also calculated. The mean doubling time is **3.23**.

Table 2 Relative Growth Rate (RGR) and Doubling Time (DT) of publication

Year	Papers	Cumulative total	Log$_e$ W$_1$	Log$_e$ W$_2$	RGR	DT	X	X^2	XY
2002	676	676	-	6.52	-	-	-7	49	-4732
2003	699	1375	6.52	7.23	0.71	0.98	-6	36	-4194
2004	726	2101	7.23	7.65	0.42	1.65	-5	25	-3630
2005	898	2999	7.65	8.01	0.36	1.93	-4	16	-3592
2006	1,062	4061	8.01	8.31	0.3	2.31	-3	9	-3186
2007	1,246	5307	8.31	8.58	0.27	2.57	-2	4	-2492
2008	1,791	7098	8.58	8.87	0.29	2.39	-1	1	-1791
2009	1,890	8988	8.87	9.10	0.23	3.01	0	0	0
2010	1,983	10971	9.10	9.30	0.2	3.46	1	1	1983
2011	2,350	13321	9.30	9.50	0.2	3.47	2	4	4700
2012	2,337	15658	9.50	9.66	0.16	4.33	3	9	7011
2013	2,397	18055	9.66	9.80	0.14	4.95	4	16	9588
2014	2,567	20622	9.80	9.93	0.13	5.33	5	25	12835
2015	2,520	23142	9.93	10.05	0.12	5.77	6	36	15120
2016	2,602	25744	10.05	10.16	0.11	6.30	7	49	18214
Total	25,744				Mean (0.24)	Mean (3.23)		280	45834

4.3 Time series analysis

A time series is a series of data points listed or graphed in time order. The time series is a sequence taken at consecutive equally spread out points in time. Therefore, it is a sequence of discrete-time data. Time series analysis comprises methods for analyzing time series data to extract meaningful statistics and other characteristics of the data. Time series forecasting is the use of a model to predict future values based on previously observed values. In this study time series analysis is applied to forecast the growth of Microbiology literature in India.

Table 3 Time series analysis of Microbiology Research

S. No.	Year	Papers (Y)	X	X^2	XY
1	2002	676	-7	49	-4732
2	2003	699	-6	36	-4194
3	2004	726	-5	25	-3630
4	2005	898	-4	16	-3592
5	2006	1,062	-3	9	-3186
6	2007	1,246	-2	4	-2492
7	2008	1,791	-1	1	-1791

8	2009	1,890	0	0	0
9	2010	1,983	1	1	1983
10	2011	2,350	2	4	4700
11	2012	2,337	3	9	7011
12	2013	2,397	4	16	9588
13	2014	2,567	5	25	12835
14	2015	2,520	6	36	15120
15	2016	2,602	7	49	18214
		25,744		280	45834

To arrive at assessments for future growth, Straight line equation is applied under the Time series analysis.

Straight line equation is $Yc= a+ bx$, since $\Sigma x = 0$

$a = \Sigma Y/N = 45834/ 15 = 3055.6$ $\quad$ $b= \Sigma XY/\Sigma x2 = 45834/280= 163.69$

Estimated literature in 2025 is, when $X = 2025-2008 = 17$

$= 3055.6+163.69*17 = 5,838.33$

From the above results, it is found that there is an increasing trend of research literature in the future years. Therefore, the corollary of the study is Microbiology research literature is growing in India.

4.4 Top Ranked Journals

The ranked list of journals chosen by the authors during the period 2002-2016 is shown in Table 4. The journals are arranged in descending order of article count. The journal with highest number of articles ranked number one and series continued so on. The criteria used for ranking is quantitative. The 25,744 articles are scattered over 328 journals. Bio-resource Technology Journal has emerged as the most preferred journal among the researchers of Microbiology with 1,610 (6.25%) articles followed by Applied Biochemistry and Biotechnology with 1,019 (3.95%) articles and World journal of Microbiology Biotechnology with 746 (2.89%) articles.

The top ranked journals list indicates that among the top 30 journals 13 journals are from USA and 8 journals from England sharing first and second place respectively. India shares 3 journals among the top 30 journals.

Table. 4. Top Ranked Journals

Sl.no	*Journal*	Country	Publisher	Articles	Rank
1	*Bio-resource Technology*	England	Elsevier SCI Ltd	1,610	1
2	*Applied Biochemistry and Biotechnology*	USA	Humana Press Inc.	1,019	2
3	*World journal of Microbiology Biotechnology*	USA	Springer	746	3
4	*Journal of Pure and Applied Microbiology*	India	Dr. M N Khan	677	4
5	*Research Journal of Biotechnology*	India	Research Journal of Biotechnology	620	5
6	*Indian Journal of Biotechnology*	India	National Institute of Science Communication-NISCAIR	609	6
7	*African Journal of Biotechnology*	Nigeria	Academic Journals	531	7
8	*Biomed Research International*	USA	Hindawi Publishing Corporation	503	8
9	*Process Biochemistry*	England	Elsevier Science Ltd	471	9
10	*Indian Journal of Microbiology*	USA	Springer	467	10
11	*3 Biotech*	USA	Springer	405	11
12	*International Journal of Systematic and Evolutionary Microbiology*	England	Society for General Microbiology	388	12
13	*Plant Cell Tissue and Organ Culture*	Netherlands	Springer	372	13
14	*Applied Microbiology and Biotechnology*	USA	Springer	356	14
15	*Current Microbiology*	USA	Springer	331	15
16	*Biosensors Bioelectronics*	England	Elsevier Advanced Technology	306	16
17	*Journal of Basic Microbiology*	USA	Wiley-Blackwell	305	17
18	*Journal of Medical Microbiology*	England	Society for General Microbiology	288	18
19	*Journal of Chemical Technology and Biotechnology*	USA	Wiley-Blackwell	287	19

20	*Journal of Clinical Microbiology*	USA	American Society for Microbiology	275	20
21	*Annals of Microbiology*	USA	Springer	275	20
22	*Antimicrobial Agents and Chemotherapy*	USA	American Society for Microbiology	271	21
23	*Biotechnology Letters*	Netherlands	Springer	258	22
24	*Biochemical Engineering journal*	Netherland	Elsevier science	252	23
25	*Journal of Biotechnology*	Netherland	Elsevier science	244	24
26	*Biomass Bioenergy*	England	Pergamon-Elsevier Science Ltd	244	24
27	*Journal of Applied Microbiology*	USA	Wiley-Blackwell	238	25
28	*Frontiers in Microbiology*	Switzerland	Frontiers Media	238	25
29	*BMC Genomics*	England	Biomed Central Ltd	233	26
30	*International Bio-deterioration Biodegradation*	England	Elsevier Science	232	27

4.5 Bradford's Law of Scattering

Bradford's Law of Scattering is a bibliometric law formulated by Samuel Clement Bradford and coined by BC Vickery. Samuel Clement Bradford, a chemist and chief librarian at the Landon Science Museum, has made a statistical analysis of two geophysics bibliographies, the Current Bibliography of Applied Geophysics (1992-1931) and the Quarterly Bibliography of Lubrication (1931-1933). Bradford Law of scattering is used as a tool to study the output of journals. Bradford's Law of Scattering states the quantitative connection between journals in this law the journals are arranged in descending order of productivity and divided into equal zones. Where the number of periodicals is distributed in the nucleus and succeeding zones, these zones will be 1: n: n2, where n is a multiplier (Bradford, 1948). Hence, considering this expression into the present study, the total 25,744 articles are divided into three groups as presented in Table 6.

Table 5: Distribution of journals

Rank	No. of journals	Cumulative no. of journals	Log of Cumulative no. of Journals	No. of citations	Total No. of citations	Cumulative No. of Citations
1	1	1	0.00	1610	1610	1610
2	1	2	0.69	1019	1019	2629
3	1	3	1.10	746	746	3375
4	1	4	1.39	677	677	4052
5	1	5	1.61	620	620	4672
6	1	6	1.79	609	609	5281
7	1	7	1.95	531	531	5812
8	1	8	2.08	503	503	6315
9	1	9	2.20	471	471	6786
10	1	10	2.30	467	467	7253
11	1	11	2.40	405	405	7658
12	1	12	2.49	388	388	8046
13	**1**	**13**	**2.57**	**372**	**372**	**8418**
14	1	14	2.64	356	356	8774
15	1	15	2.71	331	331	9105
16	1	16	2.77	306	306	9411
17	1	17	2.83	305	305	9716
18	1	18	2.89	288	288	10004
19	1	19	2.94	287	287	10291
20	2	21	3.04	275	550	10841
21	1	22	3.09	271	271	11112
22	1	23	3.14	258	258	11370
23	1	24	3.18	252	252	11622
24	2	26	3.26	244	488	12110
25	2	28	3.33	238	476	12586
26	1	29	3.37	233	233	12819
27	1	30	3.40	232	232	13051
28	1	31	3.43	210	210	13261
29	1	32	3.47	208	208	13469
30	1	33	3.50	207	207	13676
31	1	34	3.53	198	198	13874
32	1	35	3.56	197	197	14071
33	1	36	3.58	191	191	14262
34	1	37	3.61	190	190	14452
35	1	38	3.64	188	188	14640
36	1	39	3.66	186	186	14826
37	1	40	3.69	184	184	15010
38	1	41	3.71	180	180	15190
39	1	42	3.74	177	177	15367

40	1	43	3.76	166	166	15533
41	1	44	3.78	165	165	15698
42	1	45	3.81	158	158	15856
43	1	46	3.83	156	156	16012
44	1	47	3.85	151	151	16163
45	1	48	3.87	149	149	16312
46	1	49	3.89	143	143	16455
47	1	50	3.91	142	142	16597
48	2	52	3.95	141	282	16879
49	**2**	**54**	**3.99**	**140**	**280**	**17159**
50	1	55	4.01	131	131	17290
51	1	56	4.03	130	130	17420
52	2	58	4.06	126	252	17672
53	1	59	4.08	122	122	17794
54	1	60	4.09	121	121	17915
55	1	61	4.11	119	119	18034
56	2	63	4.14	112	224	18258
57	1	64	4.16	110	110	18368
58	1	65	4.17	109	109	18477
59	2	67	4.21	108	216	18693
60	1	68	4.22	107	107	18800
61	2	70	4.25	104	208	19008
62	2	72	4.28	103	206	19214
63	1	73	4.29	102	102	19316
64	1	74	4.30	101	101	19417
65	1	75	4.32	100	100	19517
66	1	76	4.33	99	99	19616
67	1	77	4.34	95	95	19711
68	1	78	4.36	94	94	19805
69	1	79	4.37	91	91	19896
70	1	80	4.38	88	88	19984
71	1	81	4.39	84	84	20068
72	1	82	4.41	81	81	20149
73	2	84	4.43	80	160	20309
74	2	86	4.45	79	158	20467
75	2	88	4.48	78	156	20623
76	4	92	4.52	72	288	20911
77	2	94	4.54	71	142	21053
78	1	95	4.55	68	68	21121
79	1	96	4.56	67	67	21188
80	2	98	4.59	66	132	21320
81	3	101	4.62	65	195	21515
82	4	105	4.65	62	248	21763
83	1	106	4.66	61	61	21824
84	5	111	4.71	60	300	22124
85	2	113	4.73	59	118	22242
86	2	115	4.75	57	114	22356
87	2	117	4.76	56	112	22468

88	3	120	4.79	55	165	22633
89	2	122	4.80	54	108	22741
90	2	124	4.82	51	102	22843
91	2	126	4.84	50	100	22943
92	3	129	4.86	45	135	23078
93	2	131	4.88	44	88	23166
94	2	133	4.89	43	86	23252
95	2	135	4.91	42	84	23336
96	1	136	4.91	41	41	23377
97	2	138	4.93	39	78	23455
98	3	141	4.95	38	114	23569
99	2	143	4.96	37	74	23643
100	3	146	4.98	36	108	23751
101	1	147	4.99	35	35	23786
102	2	149	5.00	34	68	23854
103	5	154	5.04	33	165	24019
104	2	156	5.05	32	64	24083
105	1	157	5.06	31	31	24114
106	3	160	5.08	29	87	24201
107	2	162	5.09	28	56	24257
108	2	164	5.10	27	54	24311
109	5	169	5.13	26	130	24441
110	1	170	5.14	24	24	24465
111	5	175	5.17	23	115	24580
112	5	180	5.19	22	110	24690
113	3	183	5.21	21	63	24753
114	2	185	5.22	20	40	24793
115	2	187	5.23	19	38	24831
116	2	189	5.24	18	36	24867
117	5	194	5.27	17	85	24952
118	7	201	5.30	16	112	25064
119	6	207	5.33	15	90	25154
120	5	212	5.36	14	70	25224
121	4	216	5.38	13	52	25276
122	3	219	5.39	12	36	25312
123	7	226	5.42	11	77	25389
124	4	230	5.44	10	40	25429
125	2	232	5.45	9	18	25447
126	7	239	5.48	8	56	25503
127	9	248	5.51	7	63	25566
128	2	250	5.52	6	12	25578
129	8	258	5.55	5	40	25618
130	8	266	5.58	4	32	25650
131	11	277	5.62	3	33	25683
132	10	287	5.66	2	20	25703
133	**41**	**328**	**5.79**	**1**	**41**	**25744**

Table. 6 Scatter of Journals and Citations over Bradford's zone

Zone	No. of Journals	% of Journals	No. of citations	% of citations	Bradford Multiplier
1	13	3.96	8418	32.70	-
2	41	12.50	8741	33.95	3.15
3	274	83.54	8585	33.35	6.68
Total	328	100	25744	100.00	4.91

It is clear from Table 6 that the first zone (core journals) contained 13 journals with 8,418 (32.70%) articles. The second zone (allied journals) contained 41 journals with 8,741 (33.95%) articles. The third zone (alien journals) contained 274 journals with 8585 (33.35%) articles. The summary of division of zones is as below.

The Bradford's algebraic interpretation of the law is 1: n: n^2. The connection of each zone in this study is 13:41:274. Here, 13 is the number of journals in the nucleus zone and mean Bradford's multiplier is the 4.91.

Hence,

13: 13*4.91: 13*$(4.91)^2$

13: 63.83: 313.4053 > 390.2353

Percentage of Error = $\frac{390.2353-328}{328} X100$

$= 18.97\%$

The Percentage of error is high (18.97%) and therefore Bradford's law does not fit to the above data.

4.6 Application of Leimkuhler model

In this study both Bradford's law as well as Leimkuhler models are tested to verify the scattering of literature on Microbiology (Leimkuhler, 1967). Leimkuhler developed a model based on Bradford's verbal formulation as shown below:

$$R(r)= a \log (1+br)$$

Where, $r = 1,2,3\ldots\ldots$

Egghe explained the Leimkhuler model as (Egghe, 1990):

$$a = Y_0 / \log k$$

$$b = k - 1 / r_0$$

here r_0 - is the number of sources in the first Bradford group

Y_0 – the number of items in every Bradford group (all these group of items being of equal sizes), and

k – the Bradford multiplier

$R(r)$ is the cumulative number of items produced by the sources of rank 1,2,3…. r a and b are constants appearing in the law of Leimkuhler (Leimkuhler, 1980).

Egghe (1990) has shown the mathematical formula for calculating the Bradford Multiplier *k as*

$$k= (e^{y}\, y_m)^{1/p}$$

Where γ is Euler's number (e^{y} =1.781)

e = 2.718 (constant)

p = 3

If the sources are ranked in decreasing order of productivity, then y_m is the number of items in the most productivity sources.

r_0 = number of journals in Bradford's first zone

T = Total number of journals in Bradford zone

k = $(1.781*Ym)^{1/p}$ = $(1.781*1610)^{1/3}$ = **14.17**

Yo = A/P = 25744/3 = **8581.33**

r_0 =T (k-1)/(k^p-1) = 328 (14.17-1)/ (14.17^3-1)

= **1.52**

r_1= r_0*k = 1.52*14.17 = **21.53**

r_2= r_0*k^2 = 1.52*$(14.17)^2$= **305.19**

a = Yo/logk = 8581.33/log 14.17 = **7453.21**

b = k-1/r_o = 14.17-1/1.52 = **8.66**

The findings are shown in Table 7

From Table 7, the number of journals in the nucleus is found to be **1.52** and ***k*=12.31**

Table. 7. Bradford's zone of scattering

Zone	No. of Journals	% of Journals	No. of citations	% of citations
1	1.52	0.46	2629	10.21
2	52.48	16.00	14530	56.44
3	274	83.54	8585	33.35
Total	328	100	25744	100

Hence, 1.52: 1.52*14.17: 1.52*$(14.17)^2$

1.52: 21.53: 305.19> 328.24

Percentage of error = $\frac{328.24-328}{328} X100 = \mathbf{0.073}\%$

Hence, it can be noted from the above calculations that the percentage of error is very negligible and Bradford's law of scattering fits very well in the present data set for Bradford multiplier *k*=14.17**.** It can also be noted from table 7 that the three zones are not exactly the 1/3rd of total citations.

4.7 Graphical Formulation

The graphical approach was developed by Brookes, which tries to verify the Verbal formulation of Bradford's Law (Brookes, 1969). The figure 1 presents the logarithmic plot of the cumulative number of journals on the horizontal (x) axis and the cumulative number of articles on the vertical (y) axis. If the distribution confirms Bradford's law it will display three characters

(i) a rapid rise at the beginning

(ii) a strong linear relation between two variables and

(iii) a ‘droop’ at the tail end indicating incompleteness of the bibliography.

Cumulative No. of Citations

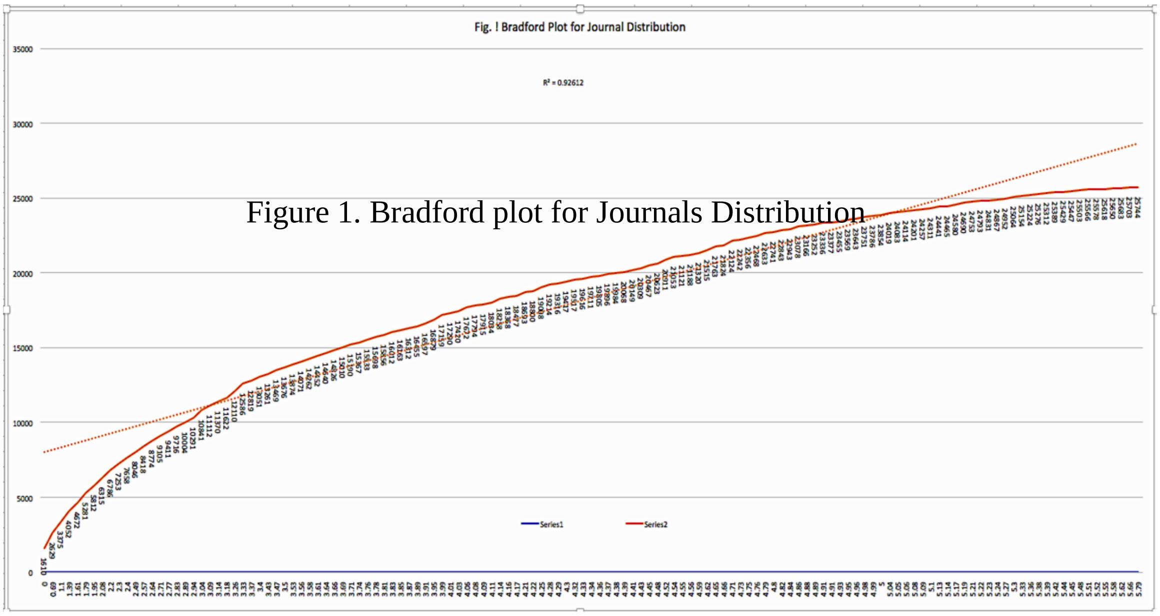

Figure 1. Bradford plot for Journals Distribution

Log of cumulative no. of Journals

Figure 1 shows Bradford’s curve with a Groos droop, where the journals are plotted against their productivity. It can be clearly estimated from the graph that less number of journals are cited highly and the maximum number of journals remained uncited.

Conclusion

Bradford’s law of scattering is a bibliometric law which helps to select the core journals in a research field. The present study attempted to apply Bradford’s law of scattering to the Microbiology literature in India for the period from 2002 to 2016. Web of Science core collection retrieved 25,744 articles distributed in 328 journals. The Journal distribution pattern of Microbiology literature does not fit Bradford’s distribution i.e. 1: n: n^2. Bradford's law of scattering states that articles in each zone should be equal which does not witness in the present study. The percentage of deviation and percentage of error are also high. Further, Leimkuhler model is applied to verify Bradford's law. It is found that percentage of error found to be negligible (0.073%) and therefore law finds valid to the data set. Graphical formulation of law is drawn and it proved all the three characteristics.

This study shall be helpful to the libraries to procure the accurate and best literature in the form of books and journals in the given research area. The study will also be useful to the researchers who are working in the field of microbiology.

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